SASKATCHEWAN RESEARCH COUNCIL

CLIMATIC CHANGE IMPACTS ON WIND EROSION IN SASKATCHEWAN, CANADA

by

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CLIMATIC CHANGE IMPACTS

ON WIND EROSION

IN SASKATCHEWAN, CANADA

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ABSTRACT

Wind erosion of soil is still a critical issue. It will become more crucial, however, in a climate affected by carbon dioxide induced warming. Wind, precipitation and evaporation are the climatic elements which influence wind erosion of soil. Wind erosion potential as measured by the climatic factor is proportional to the cube of the windspeed and inversely proportional to the precipitation-evaporation index.

The amounts and spatial distribution of the wind erosion potential of climate (climatic factor) were mapped for Saskatchewan using the normal period (1951-1980) temperature and precipitation conditions for a base as well as scenarios of a doubling of carbon dioxide with different precipitation levels as a basis for the climatic factor.

The wind erosion potential in Saskatchewan based on normal (1951-1980) conditions is intermediate to high (Chepil et al. 1962 classification) for almost two thirds of the agricultural portion of the province. The climatic factor in a climatic scenario with a doubling of carbon dioxide (with no change in precipitation) increases drastically. Over half of the agricultural area can be classified as having an intermediate to high wind erosion potential in this preceding climatic scenario. If a decrease in precipitation (70% of normal) is included in the scenario, most of the agricultural area of Saskatchewan falls into the intermediate category and the Swift Current-Shaunavon area falls into the very high category.

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1 INTRODUCTION

The seriousness of soil erosion is recognized as still being a concern (PFRA 1983; Western Provincial Conference 1984; Goudie 1981). Wind erosion is the main mechanism of soil erosion, constituting almost 60% of the total erosion by both wind and water (PFRA 1983 in B.C. Workshop 1983). Prairie soils are said to be much more susceptible to wind erosion than they are to water erosion (PFRA 1983).

Historically, soil erosion by wind was very evident in the 1930's, but several wind erosion episodes have occurred since that time. The most recent severe wind erosion occurrence was in the spring of 1980.[1] Farmers in the Saskatoon area even resorted to reseeding after these dust storms in the spring of 1980. Some of the soil lost was redeposited in ditches, looking much like the snowdrifts which accumulate during the winter. Thus it is clear that wind erosion is an old, but still continuing problem.

The spring of 1980 provided an example of the intense destructiveness of wind erosion. Brady (1974:246), says that "Not only is the land robbed of its richest soils, but crops are either blown away or left to die with roots exposed or are covered up by the drifting debris. Even though the blowing may not be great, the cutting and abrasive effects upon tender crops is often disastrous". The timing of the greatest windspeeds, being in the spring, increases the risk of erosion as spring is the period during which the land is most vulnerable as it is usually devoid of much vegetation at this time. Also, at this time, aggregate breakdown occurs, due to the frequent freeze-thaw cycles of spring and more particles are susceptible to wind transportation.

In the future years, wind erosion could increase solely due to the degradation of the tilth of the soil (Rennie 1984). The climatic factors which could induce wind erosion are high winds and low soil moisture levels. Low soil moisture levels are the result of low amounts of precipitation and high temperatures. Considering that climate is a dynamic factor, it is not sufficient to examine only current effects, but the effects of a changed climate must also be evaluated.

The other main factors controlling wind erosion are soil erodibility, soil ridge roughness, vegetative cover and unsheltered distance. The non-climatic factors are primarily a function of management and therefore are controllable. The wind erosion potential of climate must be adequately assessed in order to be able to evaluate and prescribe adequate methods of controlling wind erosion.

The cost of the effect of wind erosion on soil productivity can be measured by relating crop yield to the amounts of topsoil removed. Therefore the hazard of wind erosion can also be measured in terms of cost to the producers. Losses of topsoil decrease soil productivity, resulting in a decrease in yields. If the decreases in crop yields can be related to soil loss, the wind erosion level to produce a decrease in yields can be calculated (Lyles 1975).

[1]More recent episodes of severe wind erosion in May, 1984 have occurred since this paper was presented.

2 OBJECTIVES

The purpose of this study was to determine the impacts of climatic change on wind erosion in Saskatchewan. The normal levels of wind erosion risk imposed by climate were compared with risks associated with several scenarios of a changed climate.

The need for the examination of wind erosion hazards which would be expected with a changed climate has been strengthened by the results of studies which state that the level of atmospheric carbon dioxide is increasing and that the result will likely be a climatic warming.

The risk of soil erosion will increase with the decrease of soil moisture which, in turn, would be caused by the increased temperatures. Also, if precipitation amounts decrease in combination with increased windspeeds and temperature, wind erosion will be extremely severe.

This paper indicates the level and areas of increases of soil erosion risk in the agricultural portion of Saskatchewan.

3 LITERATURE REVIEW

Several people have recognized the effect of climate on wind erosion and have published their work, however, there is little information on the extent and severity of wind erosion in Saskatchewan.

Bagnold (1941, 1960), Chepil et al. (1962) and Woodruff and Chepil (1965) as well as Bisal and Hsieh (1966) were among the earliest pioneers studying the movement of particles of wind.

Hayes (1965), Bondy et al. (1980), Woodruff and Chepil (1965), Woodruff and Siddoway (1965), Chepil et al. (1962) and Lyles (1975, 1983) have examined the problem of wind erosion and have several publications dated from the 1960's to 1983.

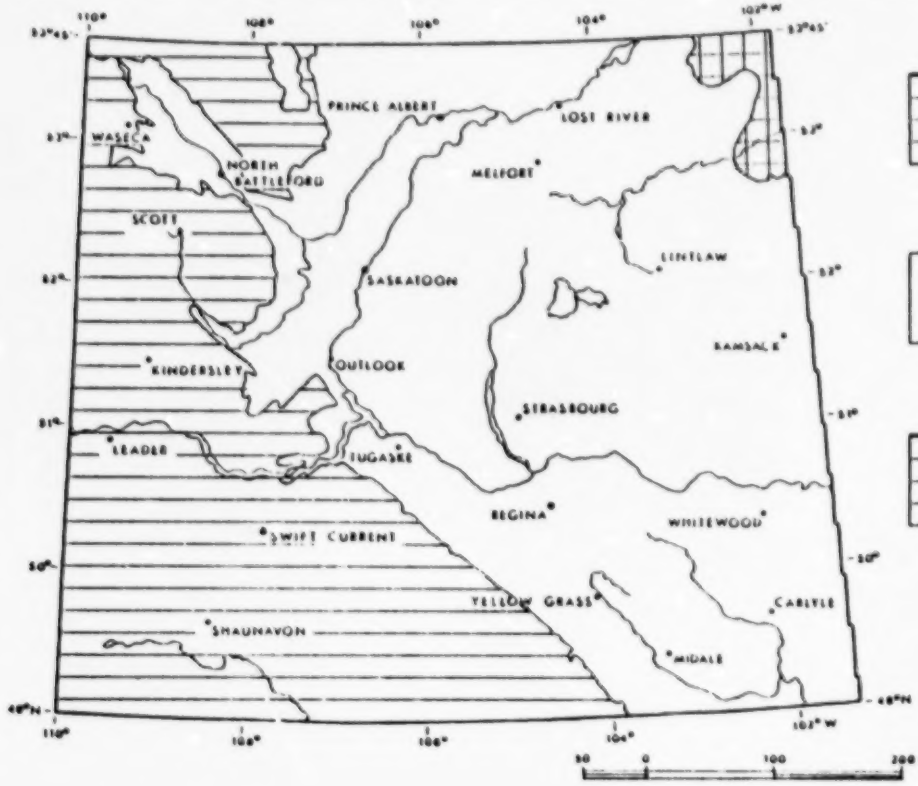
Coote (1982), Slevinsky (1984) and Gietz (1983) have examined the problem in recent years for the prairies, for Manitoba and Alberta, respectively.

Studies providing the rates of soil erosion loss attributed to wind are extremely rate. de Jong (1984) lists only two such studies, one giving a soil loss rate of 5.6 t/ha/yr and another an amount of 133 t/ha. de Jong (1984) and Black (1983) state that more data is available for the United States.

More information focussing on the movement of dust particles has been published in several other fields besides agrometeorology. Such areas are that of engineering, meteorology (air pollution) and geomorphology. For example, the Proceedings of the Fourth International Symposium on Contamination Control (1978) contain papers on dust redispersion. Other examples are Hsu (1971) in the Journal of Geophysical Research, Canessa (1977) in Pollution Engineering, and Bagnold (1960) in the International Journal of Air Pollution.

4 THE STUDY AREA AND ITS PHYSICAL SETTING

The study area is the agricultural portion of the province of Saskatchewan. Despite the overall uniformity in the topographical character displayed within the study area, however, three main physiographic divisions can be identified (Figure 1): these divisions are the Manitoba Lowlands Region, the Saskatchewan Plains Region and the Alberta Plateau Region.



Manitoba Lowlands
- lacustrine plains with elevation under 305 m.

Saskatchewan Plains
- lacustrine deposits, till plains and moraines with elevation from 305 m. to 732 m.

Alberta Plateau
- uplands with dissected plateaus, and rolling morainic hills separated by extensive till and lacustrine plains.
- mainly over 610 m.

Figure 1. Physiographic regions of southern Saskatchewan (Magill 1980 based on Richards and Fung 1969).

5 DATA AVAILABILITY AND METHODOLOGY

An index, termed the wind erosion climatic factor in the literature, is used to characterize the wind erosion potential of a climate at a particular location relative to Garden City, Kansas, which has an annual factor of 100% based on long-term climatic data. The climatic factor is directly proportional to the cube of the mean annual windspeed and inversely proportional to the square of the effective soil moisture. The Thornthwaite precipitation-evaporation index is used to represent the effective soil moisture as it requires only the readily available data.

The equation for the climatic factor as given by Lyles (1983) was the equation used for this study. The equation for computing the climatic factor is as follows:

$$C = 386 \frac{\bar{u}_z^3}{\left[\sum_{i=1}^{i=12} 10\,(P-E)_i\right]^2}$$

where: C is the annual climatic factor

$\bar{u}_z$ is the average annual windspeed in metres per second at a height of 9.1 m, i represents months, E is evaporation and:

$$10\,(P-E) = 115 \left(\frac{P/2.54}{1.8T+22}\right)^{10/9}$$

$P \geq 1.27$ cm

$T \geq -1.7^{o}C$

where P is normal monthly precipitation (in cm) and T is normal monthly mean temperature (in ^{o}C) (Lyles 1983).

Lyles (1983) used wind data measured at, or adjusted to 10 m instead of the 9.1 m specified in the equation. All of the stations used for wind data in this study have wind measured at 10.1 m.

If P is less than 1.27 cm, 1.27 cm is used. Also, if T is less than -1.7°C, -1.7°C is used. The precipitation limit prevents the climatic factor from becoming unreasonably large in desert climates. The temperature limit overcomes the problem of dealing with negative numbers in computing the precipitation-evaporation index. This equation was selected as it appeared to be explained most carefully and because there were comparable factors calculated for the states adjacent to the border of southern Saskatchewan. Also an important advantage of this method is that it can be used with readily available data.

The climatic factor was calculated for the study area using the 1951 to 1980 climatic normals (Environment Canada 1982). The network of stations used (Figure 2) was selected for its representativeness and completeness (Magill 1980).

The values and distribution of the climatic factor calculated using the 1951 to 1980 normals illustrate the wind erosion risk of this recent standard period of time. The wind erosion risk levels and distributions are determined for several scenarios of changed climate. Williams (1984b) and Magill (1980) provide descriptions of the climate of the study area. The climatic elements of importance to wind erosion are wind velocity, temperature and precipitation, including combinations of two sets of increased temperatures (with 2x, 4x CO_2) and three sets of precipitation amounts (70%, 100%, 130% of normal precipitation).[2]

The maps of wind erosion potential are compared to determine the

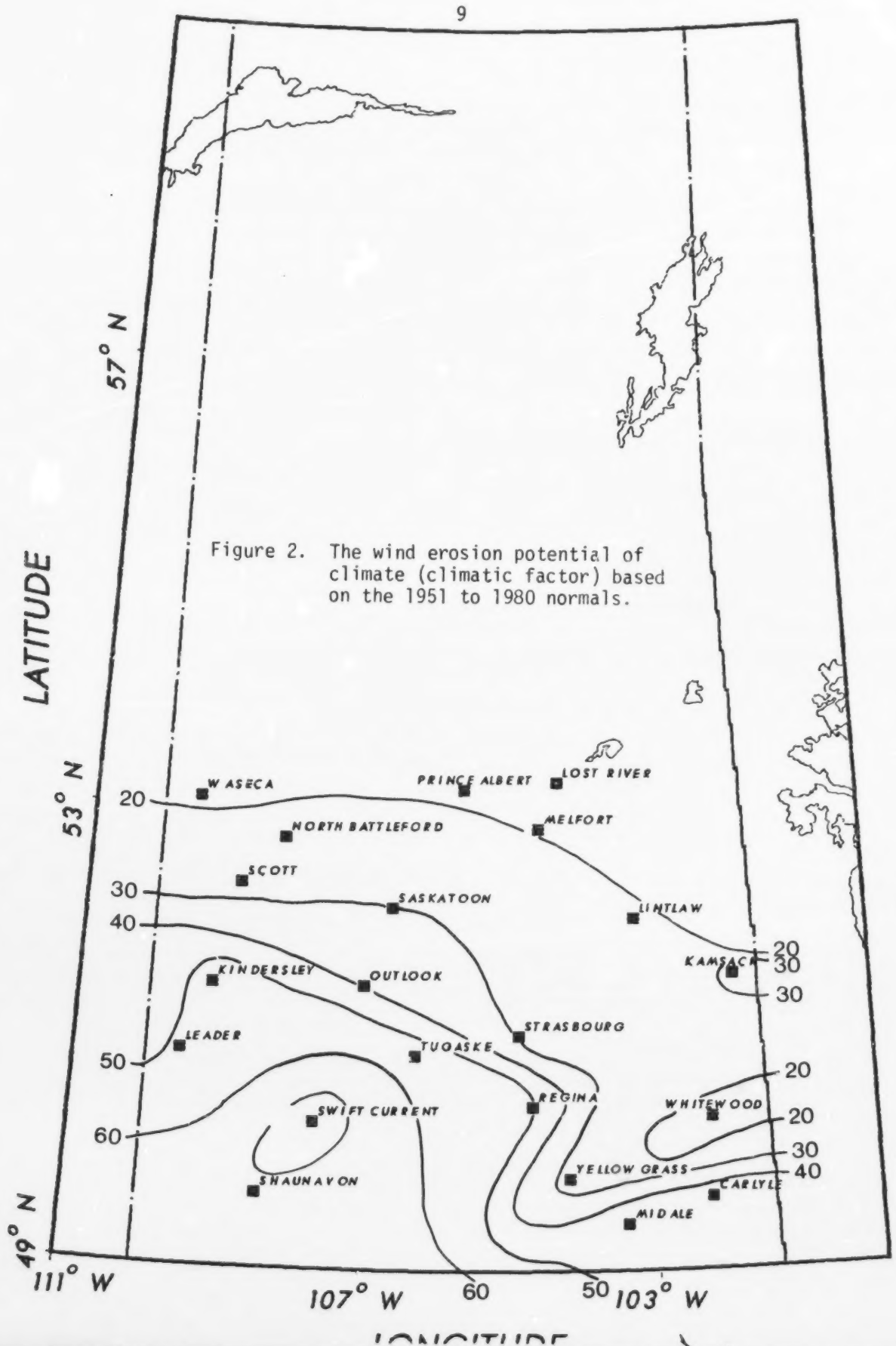


Figure 2. The wind erosion potential of climate (climatic factor) based on the 1951 to 1980 normals.

areas of greatest risk during each scenario of climate change and the rate of shift of the isopleths.

Future methods to use could include the calculation of climatic factors for wet years and for dry years as well as for years during which conditions of blowing dust are documented in the literature (Williams 1984a, personal communication). Such years are 1934, 1936, 1937, 1961 and 1977. Isolated outbreaks of blowing dust were reported during 1957 to 1963.

This method will produce factors which reflect conditions which we know were favourable or hazardous. When compared to the climatic factors based on the climatic change data, one will be able to determine how much more hazardous wind erosion could become. For example, the climatic factors for 1980 represent conditions which did result in much soil loss. If conditions under a changed climate are at or above this level, they too would bring about a significant soil loss.

Probabilities of soil erosion can be determined by finding the number of years with certain hazardous levels of the climatic factor, and by the number of days per year with blowing dust.

The application of the model of the relationship of wind erosion to wind and the precipitation-evaporation index has several problems. They are as follows:

- The mean windspeed, rather than hourly or extreme windspeeds are used. Most dust storms appear to occur during gust conditions and the mean wind conditions underestimate these extremes. Hourly windspeeds (for the Saskatchewan stations) are 3.6 to 8.6 times greater (mean of 4.4 times) than mean monthly speeds.

- Is the wind at 10 m an adequate estimator of the shear stress exerted by the wind on the soil particles? Perhaps the wind at a level of about 0.1 m should be used. The windspeeds at 0.1 m would be only about one-third the speeds at 10 m (using the power law profile for neutral stability for a smooth underlying surface; Haltiner and Martin 1957:232). The daily wind run recorded at 0.5 m at stations with evaporation pans could be of some use.

- The soil erosion during winter is likely underestimated. When there is an inadequate snowcover, soil erosion does occur. Even with a moderate snowcover, knolls soon become bare within only a short interval of drifting time and become susceptible to wind erosion.

- The precipitation-evaporation index is an inadequate measure of the effective soil moisture (i.e. effective in providing sufficient cohesive force). Perhaps another, more direct measure would be more suitable. Also, even after a rainfall, the upper soil layer can dry within hours, especially under warm sunny conditions and the soil is again susceptible to blowing. Thus, the soil may be protected from wind erosion by the cohesive forces of moisture for only a short time during and after a rain. During a rainfall, however, considerable detachment of particles can occur due to the impact of rain drops, leaving more particles detached and ready to be transported by wind.

- The model is difficult to validate because there is hardly any measured wind erosion data (refer to literature review section) and most of that being for the United States. Perhaps proxy data from the air pollution work could be used until more measurements are made. This work would be an indication of the particles in suspension, at least.

In summary, this method seems to be one of the best available at this time, especially in terms of its data requirements and suitability for use over a large area. Due to the limitations of the model, there will be preliminary discrepancies, possibly negative, from reality.

[2]The temperature data for carbon dioxide induced warming were abstracted from Manabe and Stouffer (1980). Arbitrary precipitation differences were used as sufficient information on changes in precipitation was not available.

6 PRELIMINARY RESULTS

The amounts and distribution of the climatic factor of wind erosion based on the climatic normals of the 1951 to 1980 period is shown in Figure 2. Using the classification developed by Chepil et al. (1962) (very low as 0-17%, low as 18-35%, intermediate as 36-71%, high as 72-150% and very high as over 150%) one can see that only the northern fringe of the agricultural area rates as very low and most of the southwest rates in the intermediate category. Only the area around Swift Current reaches into the high category. The southeast portion of the study area ranges into the intermediate level.

The wind erosion potentials (as indicated by the climatic factor) for several climate change scenarios are shown in Figures 3, 5, and 7 to 10. Normal windspeed data were used for all of the calculations.

The wind erosion potential with a doubling of carbon dioxide is shown in Figure 3. In comparison to the "normal" wind erosion levels, several increases are evident, especially in the southwest. There is a definite northward shift of the isopleths and the gradient has almost doubled. Also, the area with a level of over 60% has increased from less than one quarter of the study area to almost one third of the area.

Figure 4, the percentage change of wind erosion potential with the doubling of carbon dioxide as compared to the wind erosion potential with the normals, is useful in comparing Figure 3, the doubling scenario with Figure 2, the normal period conditions. The percentage change of the normal period wind erosion potential to the potential in a climate scenario with a doubling of carbon dioxide and decreased precipitation (70% of normal) is shown in Figure 6.

The percentage increases (for the normal to doubling of carbon dioxide

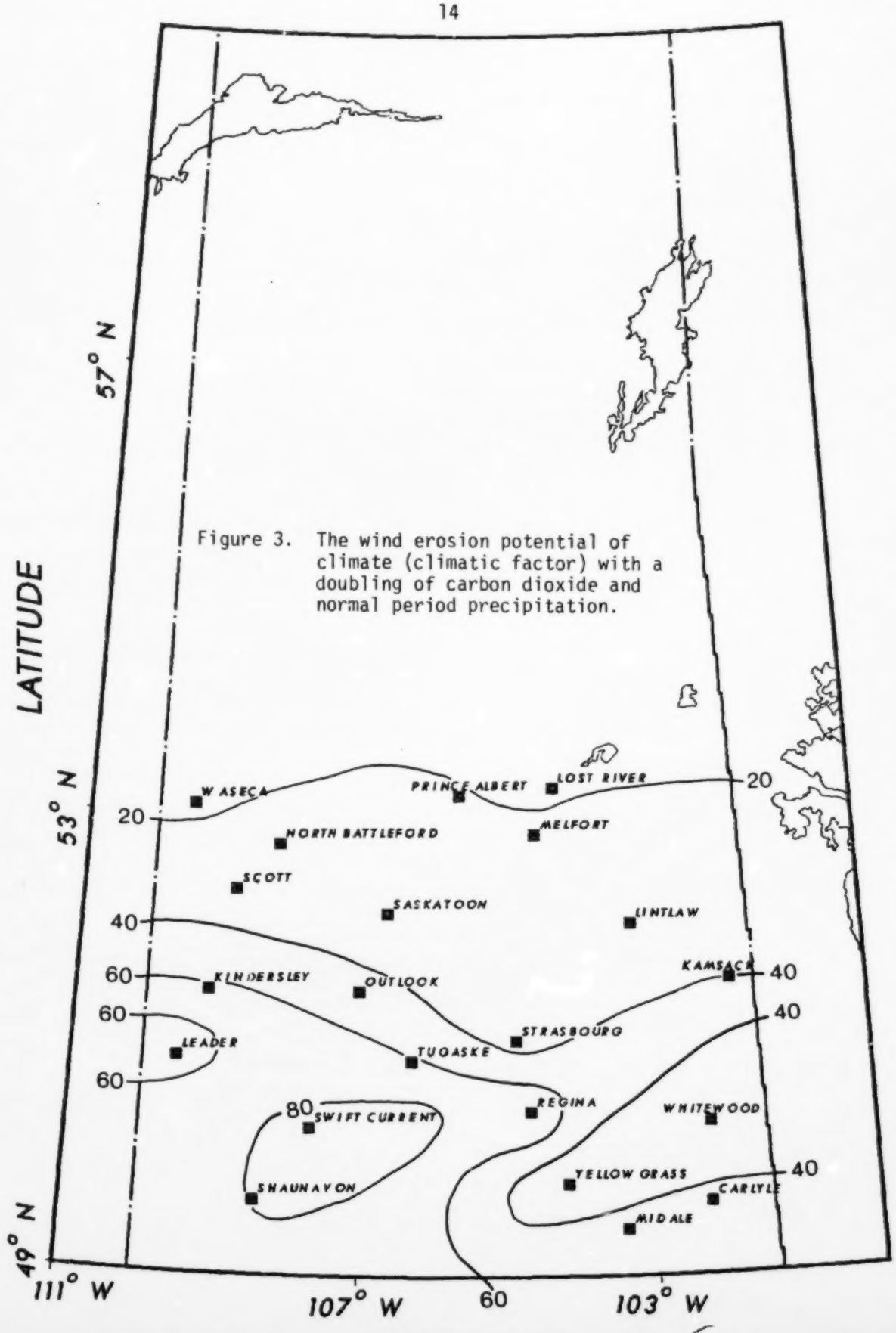


Figure 3. The wind erosion potential of climate (climatic factor) with a doubling of carbon dioxide and normal period precipitation.

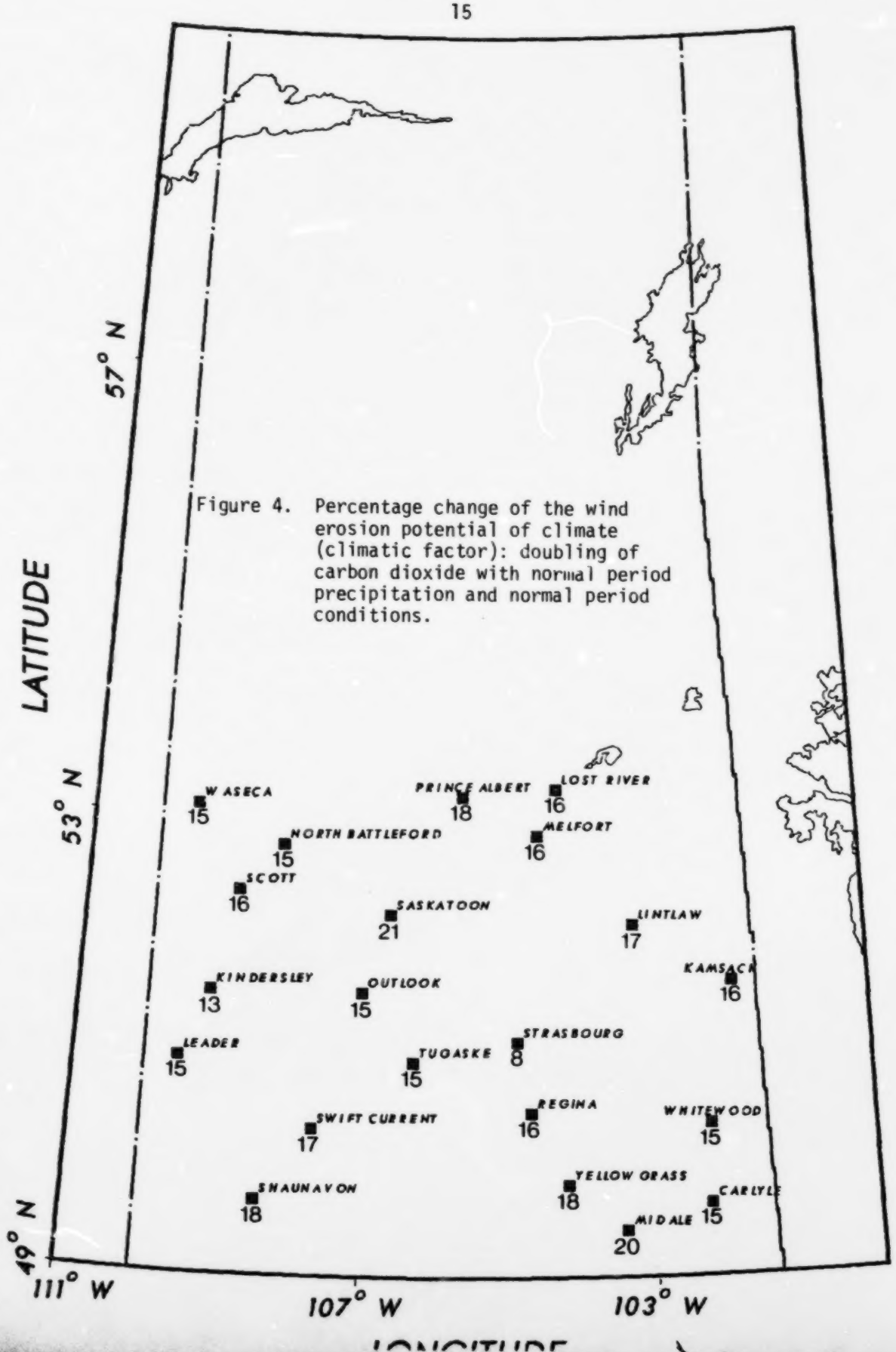


Figure 4. Percentage change of the wind erosion potential of climate (climatic factor): doubling of carbon dioxide with normal period precipitation and normal period conditions.

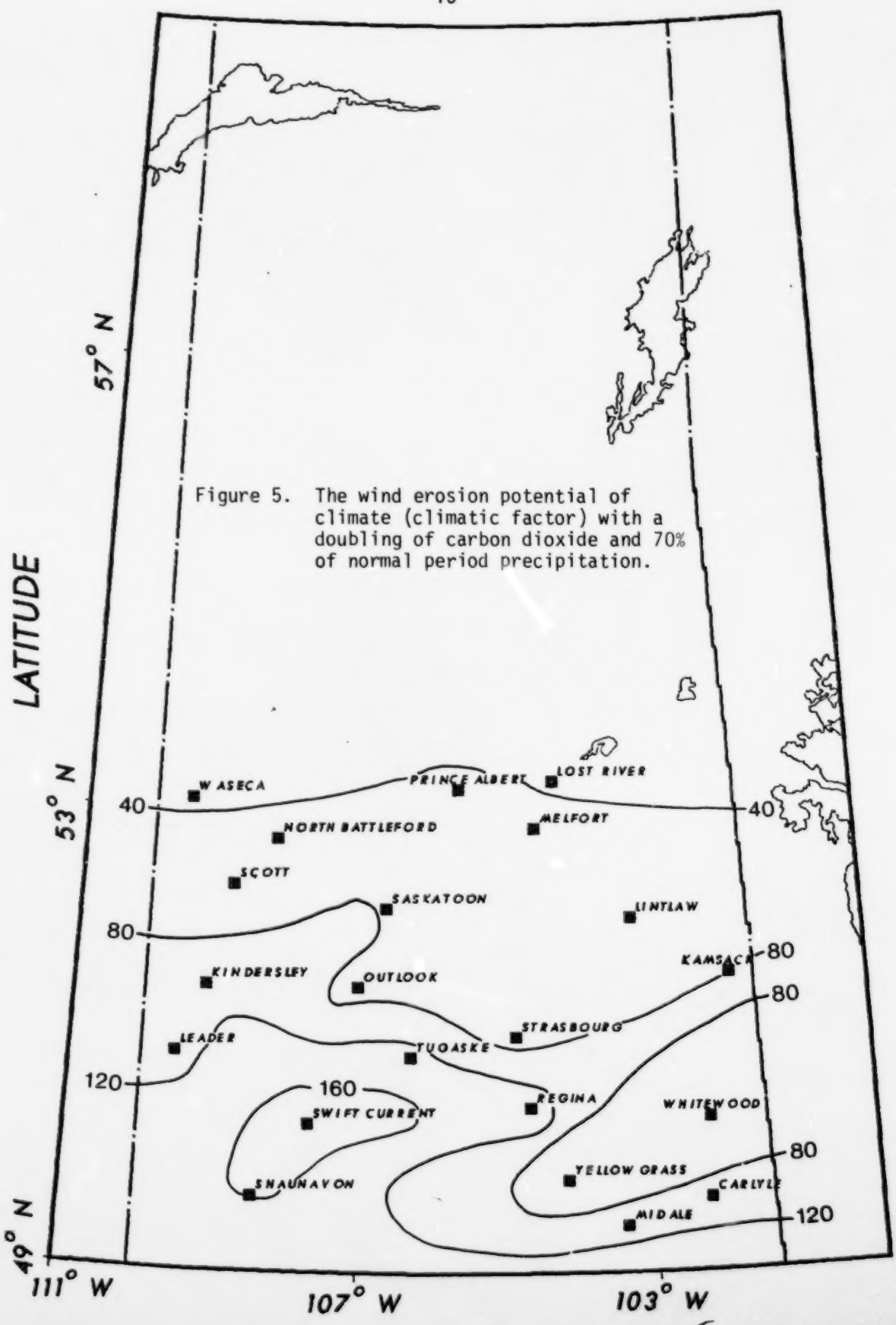


Figure 5. The wind erosion potential of climate (climatic factor) with a doubling of carbon dioxide and 70% of normal period precipitation.

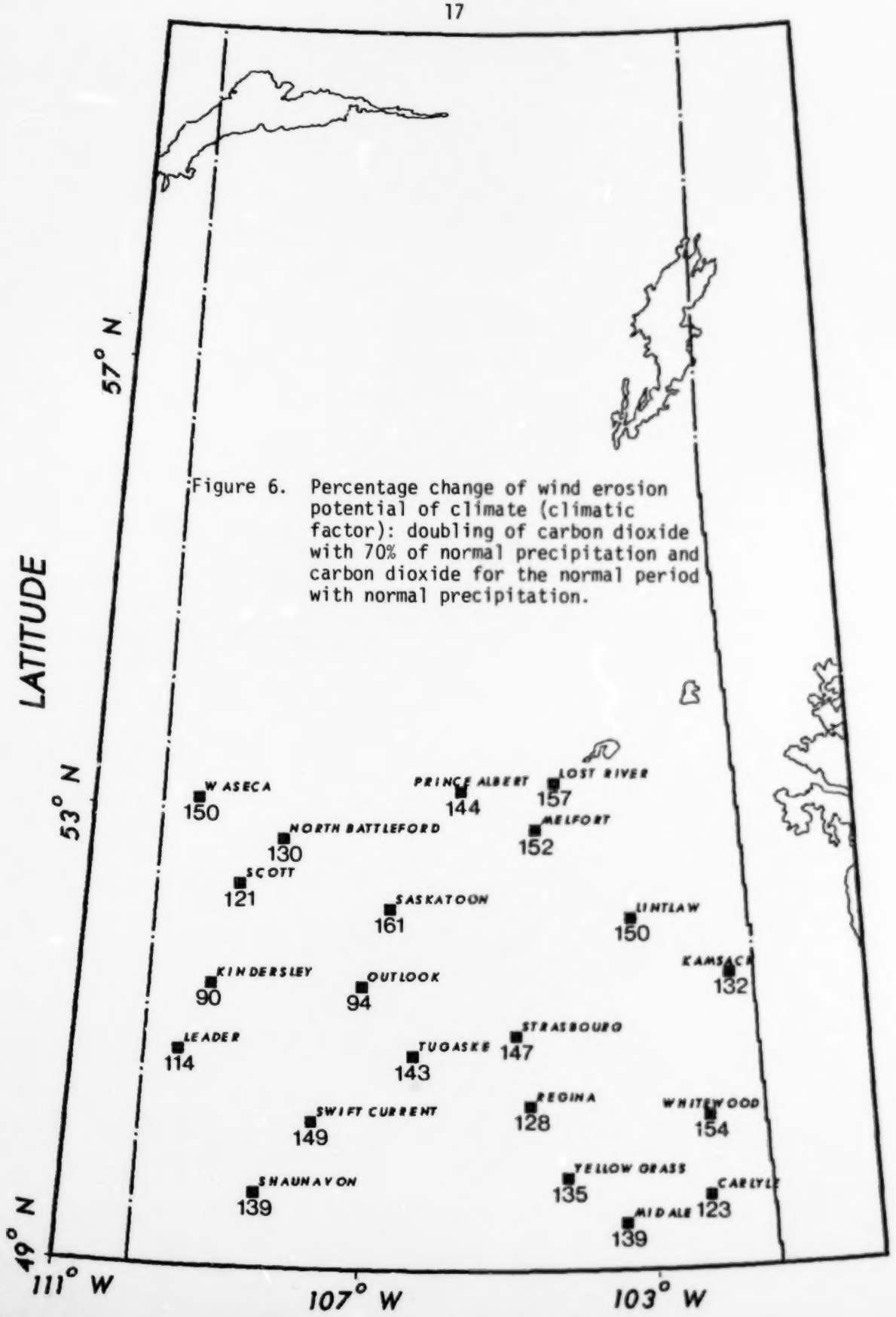


Figure 6. Percentage change of wind erosion potential of climate (climatic factor): doubling of carbon dioxide with 70% of normal precipitation and carbon dioxide for the normal period with normal precipitation.

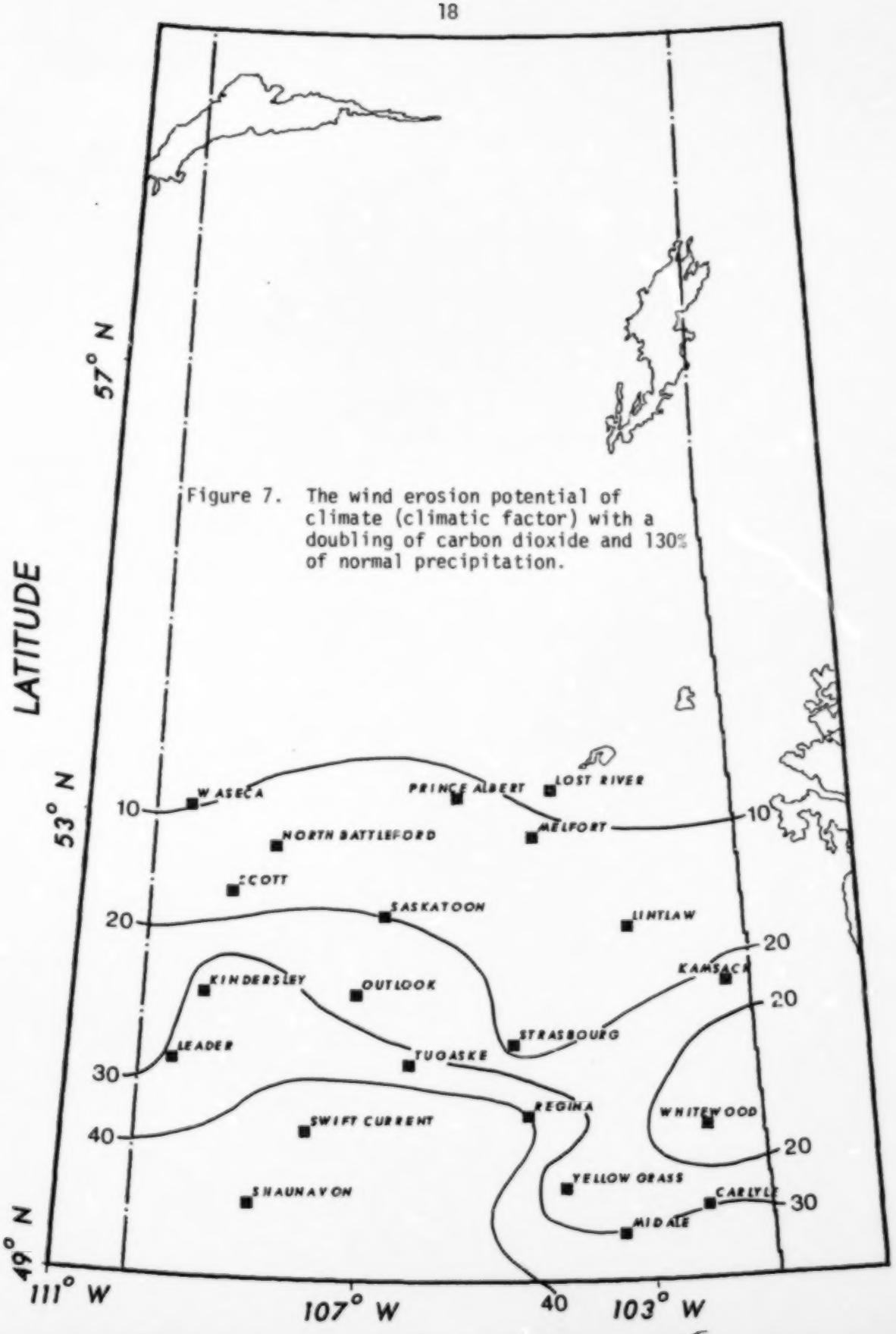


Figure 7. The wind erosion potential of climate (climatic factor) with a doubling of carbon dioxide and 130% of normal precipitation.

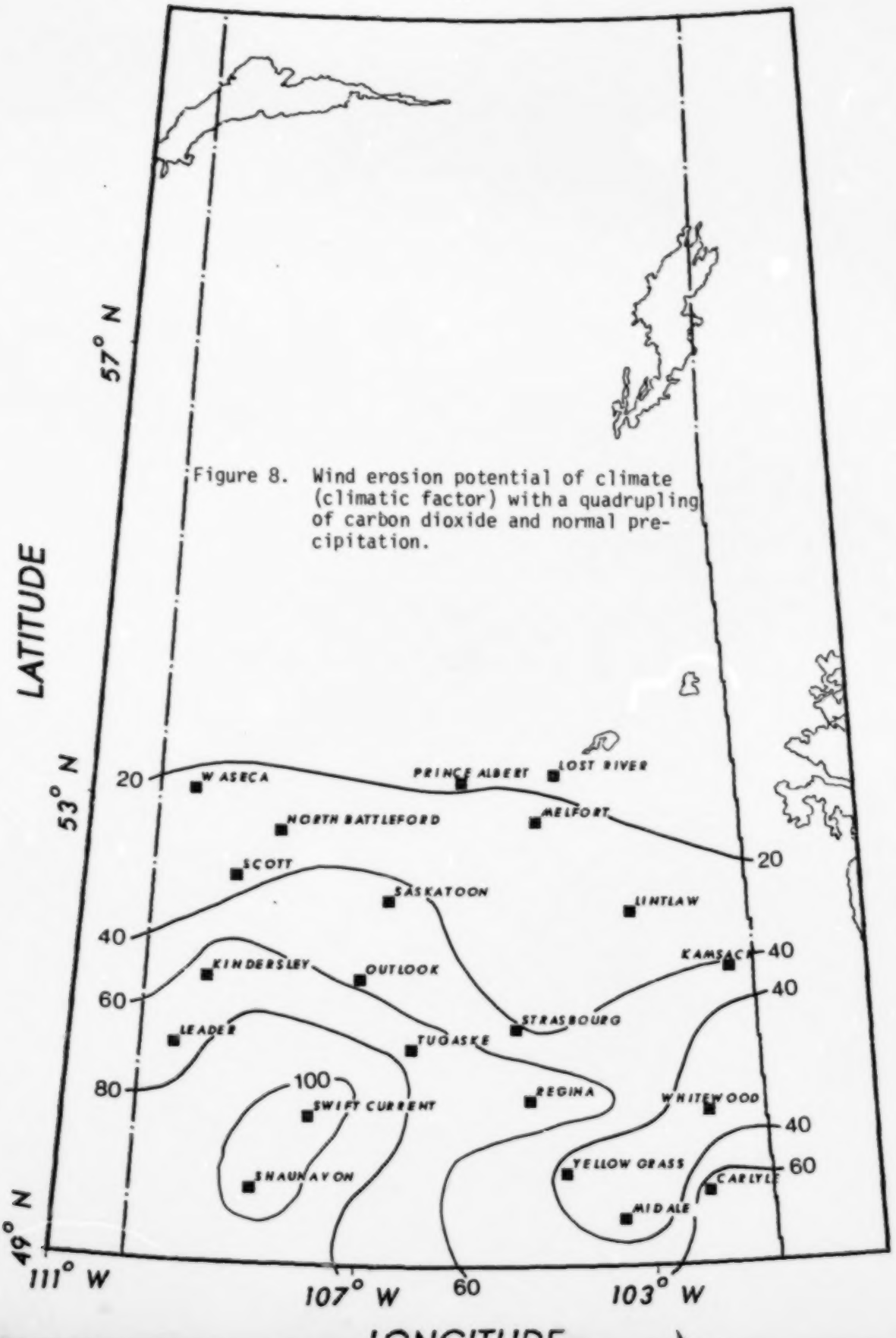


Figure 8. Wind erosion potential of climate (climatic factor) with a quadrupling of carbon dioxide and normal precipitation.

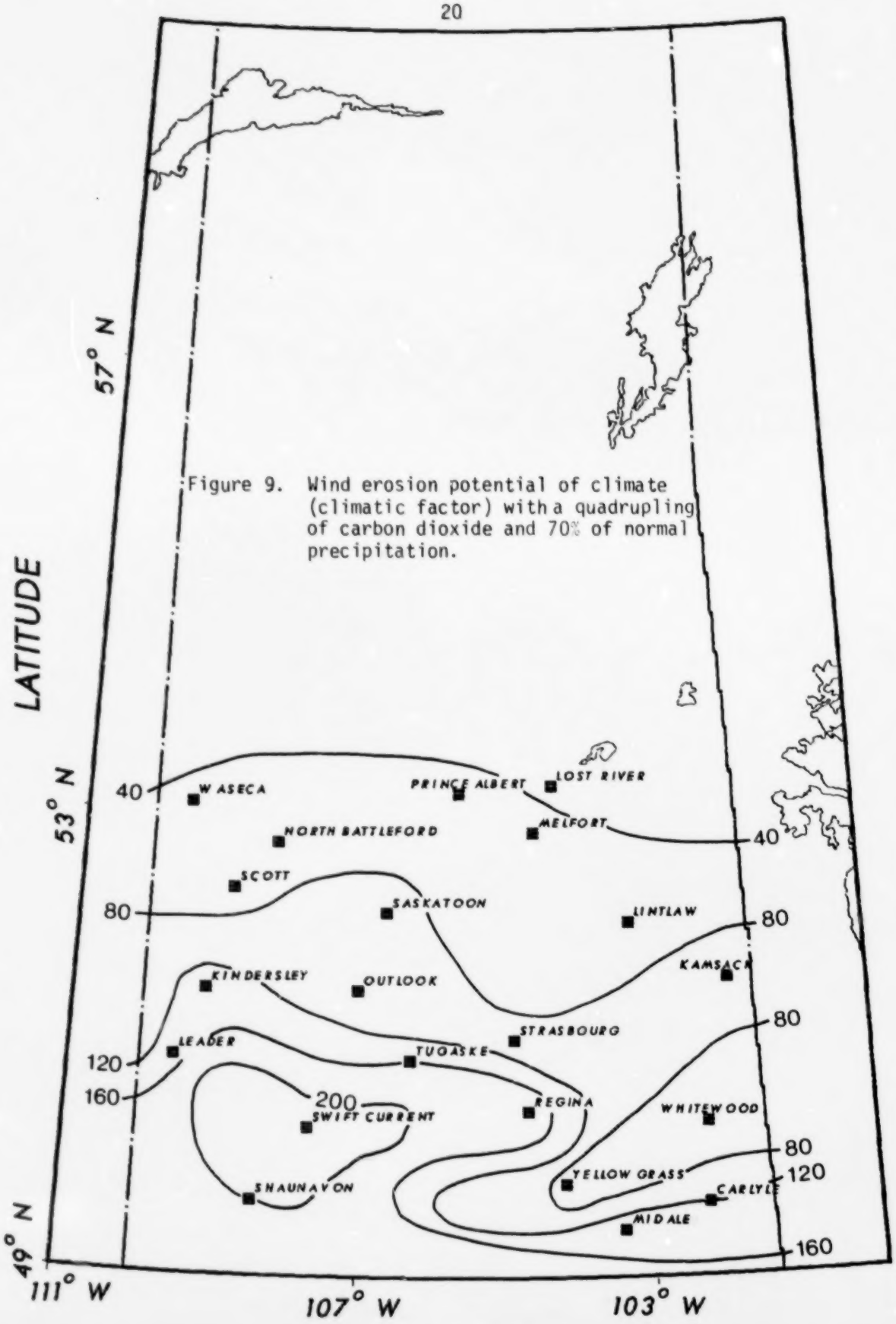


Figure 9. Wind erosion potential of climate (climatic factor) with a quadrupling of carbon dioxide and 70% of normal precipitation.

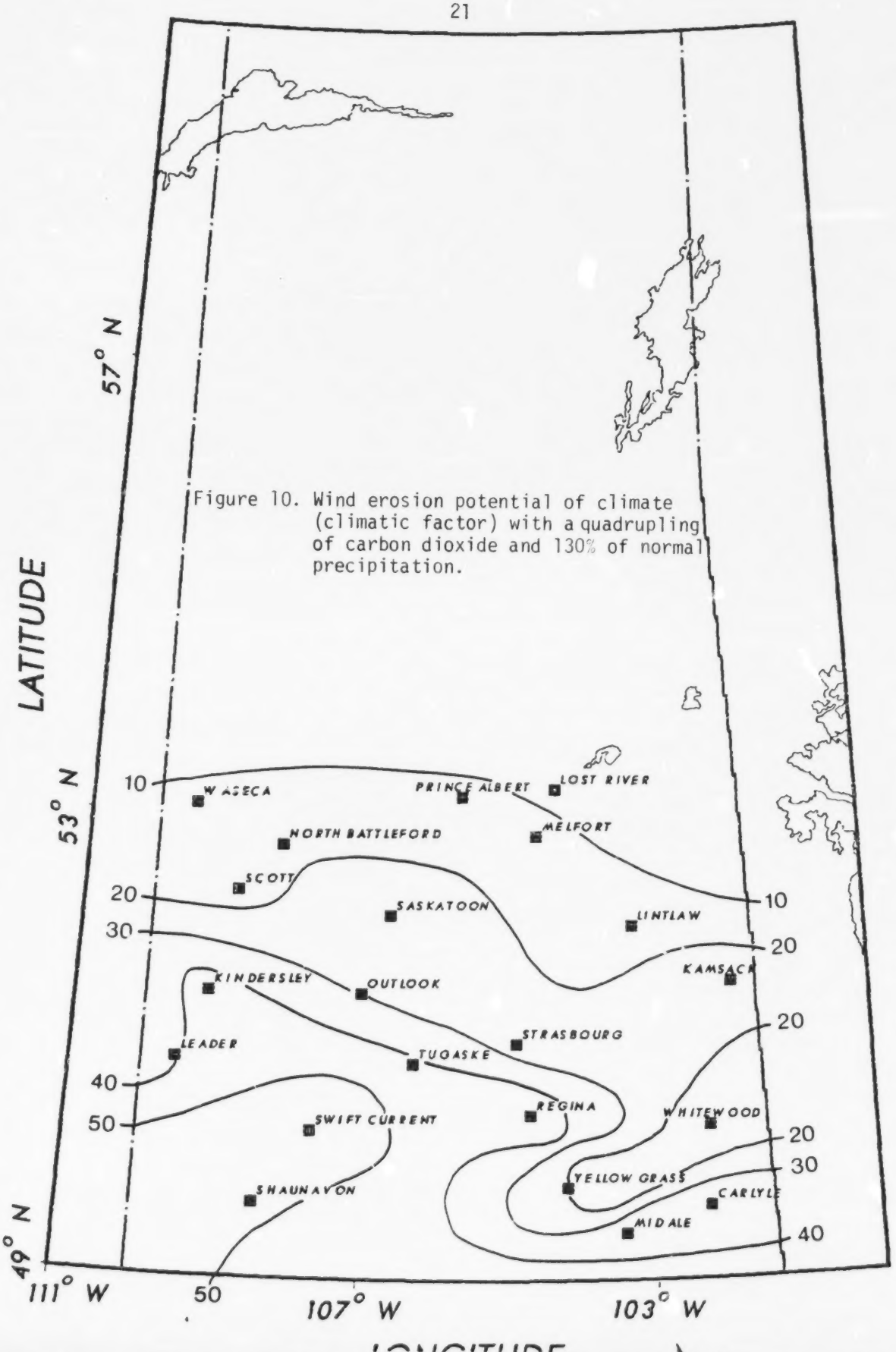


Figure 10. Wind erosion potential of climate (climatic factor) with a quadrupling of carbon dioxide and 130% of normal precipitation.

scenario, Figure 4) range from 15% to 16% in the north to 18% to 20% in the south, although the highest degree of change is 21% at Saskatoon just north of the central portion of the study area.

The climatic factors of wind erosion under a climate affected by a quadrupling of carbon dioxide and no change in precipitation (i.e. normal precipitation) is illustrated in Figure 8. A quadrupling of carbon dioxide was considered primarily for the determination of the sensitivity of the model. In comparison to the "normal" wind erosion potentials, there is a definite northward shift in the isopleths in Figure 8 and they appear to have a more twisted pattern. The levels have undergone an increase of more than 20% over most of the south. Under the influence of this type of changed climate, over half of the agricultural area of Saskatchewan would have an intermediate to high level of wind erosion risk as compared to only about one-third normally being in this category.

Also, at least one-third of the study area would be subjected to a high risk. There is a jump in the climatic factor of over 34% to a high of 48% from that of the normal period. Also, the change from one location to another is almost twice as large as normal.

Aspects yet to be assessed:

- Past levels of wind erosion risks in dry and in wet years.

- Erosion potential with an increase of wind. As temperature gradients increase, steeper gradients of pressure will result, causing a greater degree of wind activity. Also a stronger degree of turbulent convective motion could result, especially during the hotter afternoons (assuming a greater diurnal difference in temperature). Severe wind erosion during a dry afternoon could take place.

- Examination of the frequency of freeze-thaw cycles and wind erosion.

7 CONCLUSIONS

This study increased the knowledge of the effect of climate on wind erosion in Saskatchewan as well as documenting the exploration of wind erosion characteristics with several scenarios of a changed climate.

The wind erosion problem is an area of deficient knowledge, understanding of this problem must be increased, not only in the field of soil science, but also in agroclimatology and resource conservation.

Also, it must be stressed that wind erosion is not only a problem of the past (in the thirties), but is a continuing problem which will most likely become increasingly critical.

Changnon (1983) noted that there is a general upward trend in the frequency of dust storms in Illinois with current agricultural practices such as fall plowing, larger fields and fewer hedgerows. Similar practices are taking place in Saskatchewan. With the possibility of warmer and drier climatic conditions, the need for soil conservation practices will intensify.

8 RECOMMENDATIONS

Measurements of the rates of soil erosion are needed as verification of wind erosion models is indeed tenuous until such data exists.

Further work on the deficiencies of the wind erosion models as listed in the methodology section are needed. The model could also be tuned more carefully to Saskatchewan's conditions.

The study emphasizes the need to escalate action on improved soil conservation and the dissemination of knowledge required to implement such soil conservation practices.

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